ANALYSIS OF THE BEHAVIOR OF SEA TURTLES BY USING DATA LOGGERS

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ABSTRACT

Recent telemetric studies on marine animals have given various knowledge about their behavior. Two new devices presented here are under development. One is MR logger which measures magnetic fields and accelerations and the other is CCD logger which records visual data. We conducted field experiments of these new devices using two captive adult hawksbill turtles at the Sea Turtle Conservation Station situated Mannai Island, Thailand. Using MR logger we estimated at-sea activity, which differed between in the daytime and in the nighttime. We also reproduced turtles' swimming track using magnetic field data and acceleration data. The CCD logger recorded the scenes of around turtles, which provide visual information about turtles' surroundings.

INTRODUCTION

It is difficult to study the behavior of marine animals since they spend most of their life underwater. However, information on marine animal behavior is very important to manage and conserve their resources especially endangered animals like sea turtles. Recently, remarkable technological advances in animal-carried devices have led to new knowledge about the behavior of marine lives. The use of these devices including micro data loggers, ultrasonic biotelemetry, and platform terminal transmitters provides information such as migration pattern, swimming behavior, diving capacity, and so on (Minamikawa et al. 2000; Mitsunaga et al. 1999; Sakamoto et al. 1997). Based on these results, we are developing new techniques to interpret the underwater behavior of the marine animals. For this objective, we developed new data loggers that enabled us to reproduce animals' swimming track and to estimate their at-sea activities.

Swimming tracks are determined from heading direction calculated from magnetic field data and moving distance calculated from acceleration data. The underwater activities of animals can be estimated from acceleration data. In addition to these data, visual data provide information about surrounding environment. In this paper, we report on the field tests of these new data loggers which record magnetic field data, acceleration data, and visual data using adult female hawksbill turtles.

MATERIALS AND METHODS

We developed two types of new devices. One is a MR logger which records magnetic field data and acceleration data, and the other is a CCD logger which records visual data. The MR logger had a magneto-resistive effect sensor (MR sensor) and two accelerometers in it. The MR sensor detected 3D magnetic field. All the signals of the MR sensors and the accelerometers were converted to 12-bit digital data by A/D converter that was recorded on a 64 megabyte SmartMedia inside the logger. The logger was placed inside a titanium cylindrical tube which was pressure-resistant to a depth of 500 m. The diameter of the tube was 40.8 mm and length was 300 mm. The whole weight of the MR logger was 320 g in water. The CCD logger had a CMOS CCD device that took about 80 color pictures with 28,000 pixels and stored them in a 1 megabyte flush memory inside. The dimension of the logger was 92 mm × 40 mm × 28 mm, weighed about 155 g underwater. This prototype was pressure-resistant to a depth of 400m and was timer-controlled to take 4 pictures every one-hour. A light sensor was equipped with the logger not to click the shutter during the nighttime because this logger had no flash unit.

The experiments were conducted using adult hawksbill turtles at the Sea Turtle Conservation Station situated Mannai Island in the Gulf of Thailand on September 2001. The MR logger was attached using pedestals which bottom was sharpened for the shape of carapace. Before attachment, the shell was sanded to increase the bonding area for the adhesive. Initially, two pedestals were glued on the turtle's back with epoxy resin. In order to make loggers buoyant in case of falling off turtle's back and to make it easier to remove devices from turtles after experiments, wooden pedestal was adopted. Then MR logger was bound to pedestals with some cable ties. The CCD logger was attached with double-faced adhesive tapes. We attached also time-depth recorders (MDS-MkV/D; 40 g in water, 18 mm in diameter, 93 mm in length, Alec Electronics Co. Ltd.) and time-temperature recorders (MDS-MkV/D; 30 g in water, 18 mm in diameter, 80 mm in length, Alec Electronics Co. Ltd.) with double-faced adhesive tapes (Fig. 1). Magnetic field and acceleration data were recorded at an interval of 0.05 s. Depth and temperature data were recorded at an interval of 1 s. The MR logger recorded magnetic field in two axes of three directions; surging (X), swaying (Y) and heaving (Z) directions. Acceleration data were recorded in two axes of two directions; surging (X) and swaying (Y) directions (Fig. 2).

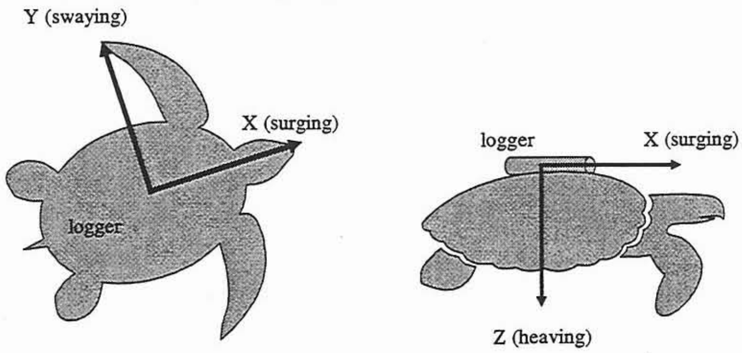

Figure 1 A sample hawksbill turtle with a MR logger (1) and a CCD logger (2) and MDSs (3: time-depth recorder, 4: time-temperature recorder).

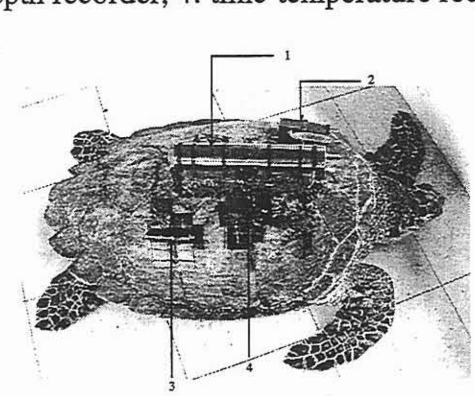

Figure 2 The direction of surging (X), swaying (Y) and heaving (Z) magnetic fields and accelerations. A MR logger recorded X, Y and Z magnetic fields and X and Y accelerations.

These devices were attached to two hawksbill turtles (*Eretmochelys imbricata*). Detailed information on these turtles is listed in Tab. 1. The experiments were conducted at the rearing pond which area was about 5 ha with about 2 m depth in the Sea Turtle Conservation Station. We released turtles in the rearing pond at 14:00 on 25 September 2001. Then we recovered loggers from them at 9:00 on 27 September 2001. Magnetic field and acceleration data in SmartMedia were downloaded in a personal computer after the experiments. Depth and temperature data were downloaded via an interface RS232C from MDSs.

Table 1: Biological and deployment data of two equipped hawksbill turtles rearing at the Sea Turtle Conservation Station in Mannai Island

Turtle no.	Sex	Age (yr.)	CCL (mm)	Body mass (kg)	Date & time of release	Date & time of recovery	Length of record (h)
HB-1	F	15	710	53.8	25 Sep 2001 14:03	27 Sep 2001 9:02	43
HB-2	F	15	680	55.4	25 Sep 2001 13:58	27 Sep 2001 9:06	43

RESULTS

MR Logger

The data were obtained for 43 hours from two MR loggers. Depth and temperature data were also obtained from MDSs. Fig. 3 shows an example of the raw data recorded by a MR logger and MDSs. This figure suggested that the turtle exhibited different diving patterns during a 24 h period. For the determination of daily activity patterns days were split into daytime (6:00-20:00 local time) and nighttime (20:00-6:00 local time). We estimated activity of animals and reproduced their swimming track using obtained data.

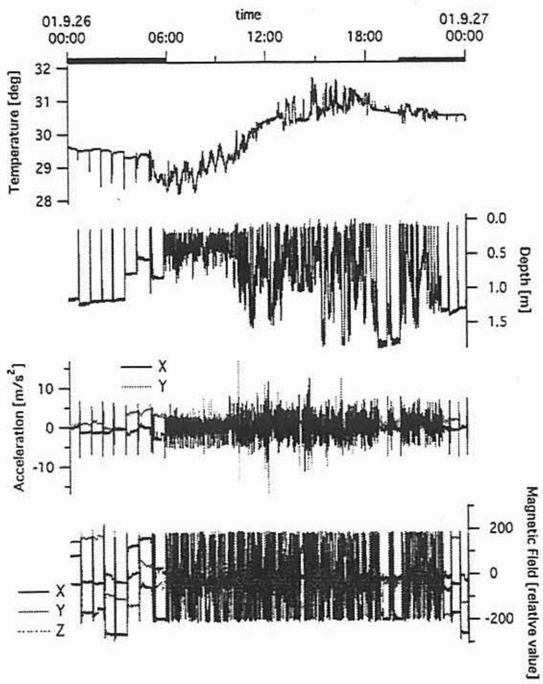

Figure 3. Examples of time series data of temperature, depth, accelerations and magnetic fields of HB-1 during a 24 h segment starting on 26 September 2001 at 00:00 h local time. Dark bars indicate nighttime (0:00-6:00, 20:00-0:00).

Estimation of Activity

Animals' activity was estimated by using acceleration data. Changes in the acceleration show changes in the power to function in the individuals. The powers to function in the individual are gravitation, buoyancy and swimming propulsion produced by turtle flippers. Changes in the activity of the turtles result in changes in the gravitation and the propulsion. Therefore, the changes in the acceleration recorded by the MR loggers can be used as an indication of the activity of the turtle. For consideration of animals' activity we calculated the standard deviation (SD) of the acceleration in every 40 data.

Calculated SDs in the daytime were almost beyond 0.5, while those in the nighttime were almost less than 0.1 (Fig. 4). The SDs when the turtles stood were very low, and maximum value was 0.07. The threshold for resting was therefore taken to be 0.07. By summing up all value beyond 0.07 it was possible to estimate the time when the turtle was active. We compared the proportion of active time for each hour in the daytime with that in the nighttime. The turtles were active in the daytime, while they were resting at most of the nighttime (Tab. 2).

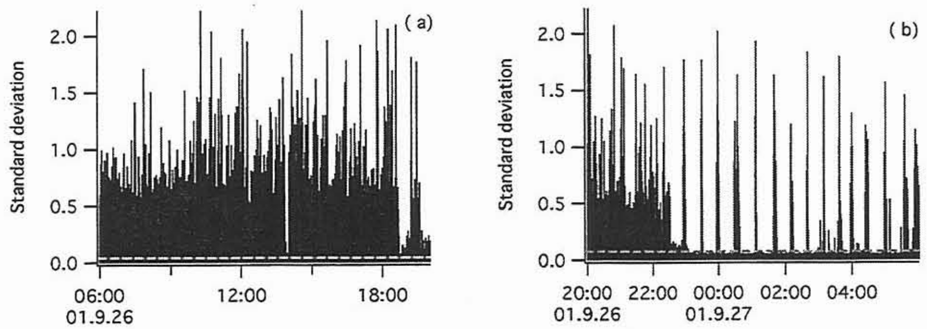

Fig. 4 Calculated standard deviation of the surging acceleration in every 40 data; a) Daytime (6:00-20:00), b) Nighttime (20:00-6:00). When values were beyond the threshold (dashed line) the turtle were supposed to be active.

Table 2: The proportion of active times of hawksbill turtles in the daytime and the night time

	Proportion of active times (% / hour)			
	Day time (6:00-20:00)		Night time (20:00-6:00)	
Turtle no.	Mean	S.D.	Mean	S.D.
HB-1	92.4	2.1	32.4	7.0
HB-2	68.6	4.3	21.3	19.9

Reproduction of Swimming Paths

Heading direction of the turtle were calculated using surging (X) and swaying (Y) magnetic field data. When a MR sensor was pointing north, the X output was its maximum value while the Y output was zero since no part of the earth's field was pointing to the left, or west. As the sensor turns clockwise toward the east, the X output diminished to zero while the Y output increased to its maximum value. With the sensor continued its clockwise turning to point due south, the X output decreased to its most negative value while the Y output return to zero (Fig. 5). The X and Y outputs of the

MR sensor could be modeled by the cos („) and sin („) functions where „ was the azimuth, referenced to magnetic north. Using this relationship the azimuth was calculated as the following equation:

$$\text{Azimuth (degrees)} = \begin{cases} 90 & (x = 0, y > 0) \\ 270 & (x = 0, y < 0) \\ 180 + \arctan(y/x) * 180\pi & (x < 0) \\ \arctan(y/x) * 180\pi & (x > 0, y > 0) \\ 360 + \arctan(y/x) * 180\pi & (x > 0, y < 0) \end{cases}$$

To reduce an influence of the vertical movements, we used the data of HB-1 recorded in ten minutes, 19:49:21-19:59:21 on 25 September 2001 (Fig. 6) when the swimming depth of the turtle was fairly constant (between 0.38 m from 0.12 m, Fig. 6b). The calculated heading direction shows HB-1 heading north moved west with several changes of direction (Fig. 6d).

Swimming distance of the turtle was calculated using surging (X) acceleration. The X acceleration shows a cyclical fluctuation (Fig. 7). This fluctuation was respected to reflect swimming propulsion produced by turtle flippers. We looked on each of peaks o f X acceleration as corresponding to one flipper and counted flipper frequencies. We supposed that the turtle moved 0.5m with one flipper and calculated swimming distance. This process was conducted in every ten seconds. We combined swimming distance with heading directions and reproduced the swimming track of HB-1 (Fig. 8).

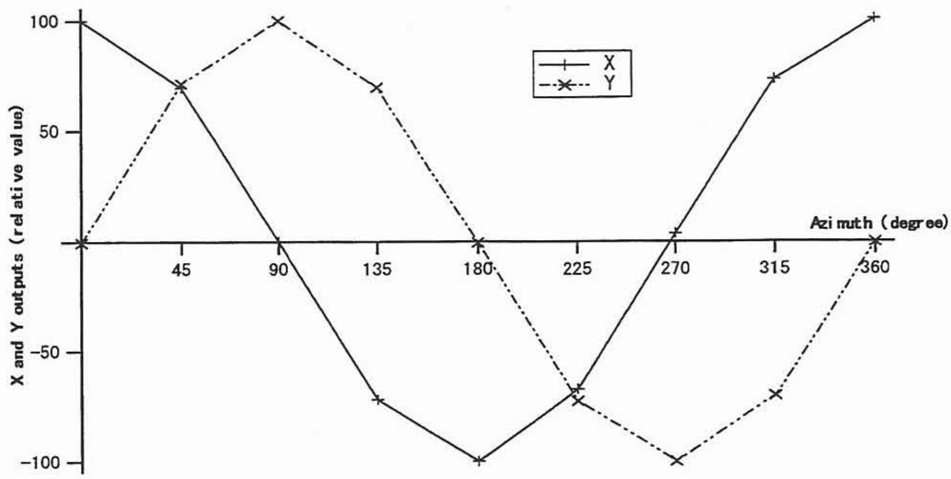

Fig. 5 MR sensor outputs (X, Y) for 360. Rotation in the level plane.

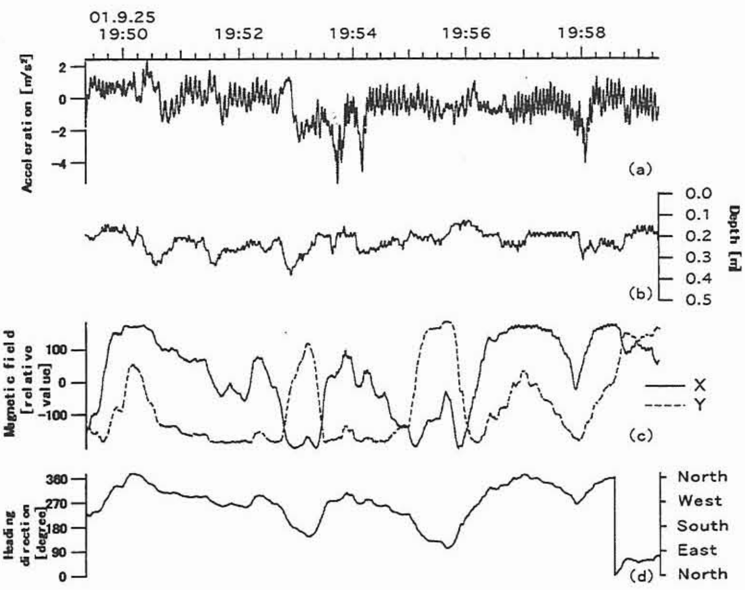

Fig. 6 Time series data obtained from HB-1 and calculated values from magnetic field. a) Time-surging acceleration records. b) Time-depth records. c) Time-magnetic field records. d) Heading direction of the turtle calculated from X and Y magnetic fields.

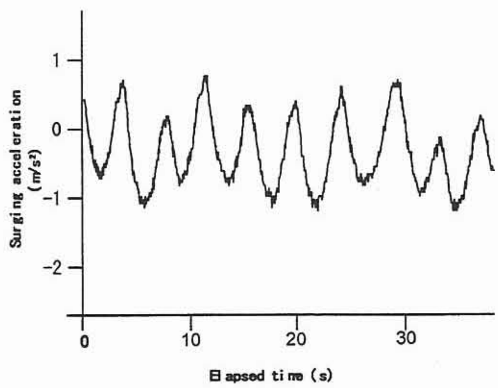

Figure 7. A surging acceleration profile of HB-1. Each sharp peak in acceleration was looked on as corresponding to one turtle flipper.

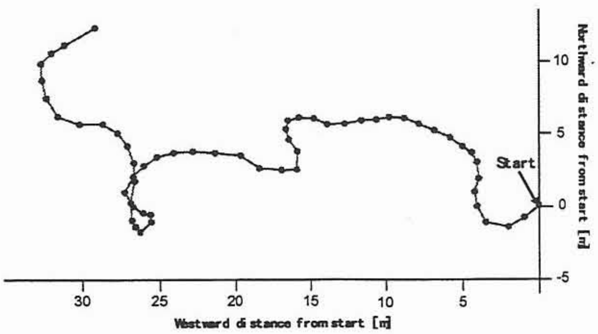

Figure 8. Reproduced swimming track during 10 minutes. The solid circles indicate the position of the turtle every 10 seconds.

CCD Logger

Two CCD loggers recorded 80 color pictures, respectively. The CCD logger was controlled to take four pictures in the interval for five seconds in every one hour by a micro controller. Figure 9 gives examples of the recorded pictures. The bottom of the pond (Fig. 9a) and the water surface (Fig. 9b) were identified.

(a)

(b)

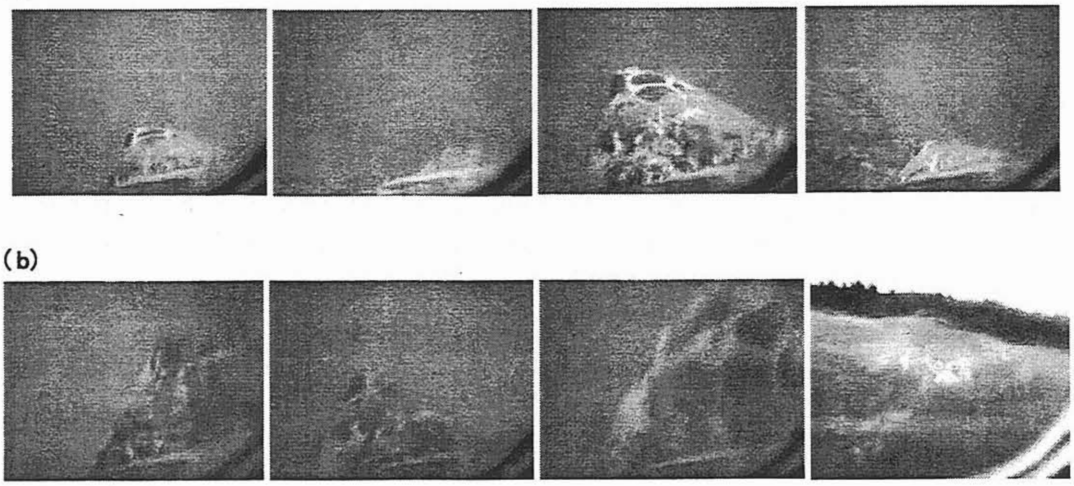

Figure 9. The pictures recorded by the CCD logger on the HB-2's back. a) The small parts of the turtle and the bottom of the pond were identified. b) The turtle was surfacing. The scene of surface was taken in the fourth picture.

DISCUSSION

Using the MR loggers we could estimate turtles' at-sea activities and reproduce their swimming track. In regard to estimation of activity, it hopes for further developments of data analyses so that a distinction between different swimming activities could be made. It may be possible, for example, to define more thresholds between particular activity levels such as foraging and traveling. Swimming distances were calculated from the flipper frequencies. Another method to calculate is necessary, however, to improve the quality of the track. The speed and moving distance can be calculated by integration of the acceleration theoretically. The accelerometer measured the accelerations with respect to changes both in the movements of turtles and in gravitational acceleration. Therefore, we need to remove the gravitational acceleration to calculate moving distance by integration of the acceleration. In this study, however, the appropriate procedures were not developed yet. In addition, actual movements of turtles are three dimensions. It is possible that swimming track in three dimensions is reproduced if the body angles of turtles can be calculated, although present study supposed turtles' movements to be made in two dimensions. Combination turtles' swimming track with their activity helps us to infer where and how they acted.

Visual data recorded by the CCD loggers provide information about turtles' surroundings. This information are useful for further understanding behavior of turtles in combination with information obtained from the MR loggers. This knowledge has a certain impact on conservative aspects: it is very important to distinguish between at-sea behaviors of different areas, because conservation plans should be well suited to the specific activities of local area, e.g. protected areas dependent on turtle habitat utilization, establishment of a preserve and particular protection of sea turtle food resources.

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